

## **The Ecology and Acoustic Behavior of Minke Whales in the Hawaiian and other Pacific Islands**

Thomas F. Norris

Bio-Waves Inc.

517 Cornish Dr.

Encinitas, CA 92024

phone: (760) 858-5656    fax: (760) 652-4878    e-mail: [thomas.f.norris@bio-waves.net](mailto:thomas.f.norris@bio-waves.net)

Award Number: N00014-10-1-0429

website: <http://www.bio-waves.net>

### **LONG-TERM GOALS**

The long-term goals of this research project are to develop and use passive acoustic methods to collect data that will improve our understanding of minke whales (*Balaenoptera acutorostrata*) in their presumed breeding habitats around the Hawaiian Islands. Ultimately, the new information and methods resulting from this project will provide a better understanding of the ecology and behavior of minke whales so that more effective management and conservation practices can be developed.

### **OBJECTIVES**

The overall objectives were to use passive acoustic methods to investigate minke whales off the Hawaiian Islands area using a unique vocalization they produce called a 'boing.' Our goal was to collect data simultaneously from two different passive acoustic systems, a quiet research vessel towing a hydrophone array, and a U.S. Navy seafloor hydrophone array located in the study site. Another goal was to develop and use new methods to detect, localize, and monitor acoustic behaviors of vocally active, but acoustically sensitive and visually elusive minke whales.

Our specific goals were to use vessel-based passive acoustic methods to collect data that would be used to estimate the density and abundance of minke whales at our study site. A second objective was to investigate minke whale acoustic behaviors including an investigation of the effects of noise from our vessel on the acoustic behavior of minke whales so that resulting biases on the line-transect surveys could be assessed. The final objective was to investigate the population structure of minke whales by comparing acoustic characteristics of boings recorded at our study area in Hawaii to other regions such as the Marianas Islands and Midway Island.

### **APPROACH**

This effort is a partnership with several collaborators and institutions working on related efforts, including Stephen Martin (SPAWAR), Len Thomas and Vincent Janik (Univ. of St. Andrews) and Eva Nosal (Univ. of Hawaii-SOEST). Bio-Waves was responsible for vessel-based surveys and validation efforts. We conducted combined visual and acoustic line-transect surveys of minke whales at our study site off of Kauai. The study site is a large (~ 1900 km<sup>2</sup>) rectangular shaped region that includes

Report Documentation Page			Form Approved OMB No. 0704-0188		
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE <b>2010</b>		2. REPORT TYPE		3. DATES COVERED <b>00-00-2010 to 00-00-2010</b>	
4. TITLE AND SUBTITLE <b>The Ecology and Acoustic Behavior of Minke Whales in the Hawaiian and other Pacific Islands</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>Bio-Waves Inc,517 Cornish Dr,Encinitas,CA,92024</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release; distribution unlimited</b>					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>Same as Report (SAR)</b>	18. NUMBER OF PAGES <b>9</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

areas of deep (up 4500 m) ocean waters located to the northwest of the island of Kauai (Figure 1). This study area was chosen because it is outfitted with several sea-floor hydrophone arrays that are part of the Pacific Missile Range Facility (PMRF). During the survey effort, acoustic data were acquired and recorded (by S. Martin) from 15 to 19 hydrophones from the BSURE seafloor array. These data were post-processed using Matlab scripts to localize calls (boings) produced by minke whales.

Visual and acoustic line-transect surveys conducted from an acoustically quiet 87 ft. motor-sailing research vessel (R/V Dariabar). A two-element towed hydrophone array was deployed throughout the survey. Boings from minke whales were monitored and processed in real-time using ISHMAEL, Pamguard and Whaletrack II software for localization, plotting, and data-logging. Visual surveys were conducted when conditions allowed the use of standard line-transect protocols. All acoustic data were recorded to hard drives for post-processing and archival purposes.

Localizations of minke whales from the towed hydrophone array were used to estimate the perpendicular distance from the survey vessel track. These and other data were imported into the program DISTANCE to estimate the density of calling animals using distance-sampling analysis methods (Thomas et al. 2010). These density estimates will be used to calculate average boing production rates of minke whales in the study area which are needed for the the spatially explicit capture-recapture methods that are being developed as part of the related DECAF effort (Marques et al 2010).

Acoustic characteristics of boings recorded during our 2010 study will be compared to boings recorded in the Marianas and Midway Islands using classification and regression tree analyses (CART). These analyses allow a simple and intuitive statistical method to compare and identify features of boings that are important in elucidating different populations or sub-populations in the North Pacific Ocean.

Other analyses of minke whale acoustic behaviors include investigation of the effects of noise from our own vessel on detection rates of minke whale boings. These data are being analyzed using a matched sample approach (e.g. paired T-test and repeated measures ANOVA) so that conditions can be adequately controlled between samples. The results of these studies will be used to examine avoidance and/or changes in vocalization rates due to noise from our survey vessel during the line-transect effort.

A related side-effort was to use a relatively fast platform to transit to the study site and localize/track minke whales using a fixed hydrophone array attached to the vessel, sonobuoys, and visual observations. A 56 ft tri-maran motor-sailer (R/V Tropic Bird) was used as a stable but quiet platform to conduct operations from. A fixed three-element array and a sonobuoy receiving and recording system were used to conduct real-time monitoring and attempt localizations. The tri-maran provided quicker transits to the study site (located approximately 30-40 nm from the nearest port) than possible with a mono-hull motor-sailing vessel.

## **WORK COMPLETED**

We conducted vessel based line-transect surveys over 4 weeks in spring 2010 in spite of extremely poor sea conditions during the 1 month period.. The line-transect effort began on 13 March and ended on 14 April 2010. A total of 13 days of survey effort consisted of four complete surveys (each 2-5 days in length) of the study site. A total of 1520 km of line-transect were completed, averaging 380 km for each survey (Table 1). Acoustic localizations of minke whales derived from this effort are now being used to calculate density estimates using distance sampling methods (see year-end report by Len

Thomas for details). These density estimates will be used to calculate an average boing rate for use in the spatially explicit capture-recapture methods (SECR). SECR is using densities of calling minke whales from the PMRF seafloor array as part of our collaborators ongoing efforts (Martin, 2010).

The localization/validation work on the R/V Tropic bird was conducted during the last week in February 2010, prior to the start of the line-transect surveys. Several days were dedicated to setting up and testing equipment on the vessel in the harbor and in calm waters nearby. Two days of field effort inside the study area were completed before deteriorating sea conditions forced an end to the project (note: we were able to work in spite of a serious Tsunami warning on the final day of effort).

### **Presentations, Conferences and Workshops Attended**

The preliminary results of our 2010 field effort were presented at the 2nd International Conference on the Effects of Noise on Aquatic Life Conference, Cork, Ireland in (Norris et al. 2010). Our work also has been accepted as an oral presentation at the 2nd Pan-American/Iberian Meeting on Acoustics, Cancun, Mexico 15-19 November 2010. In late August, 2010, Tom Norris attended two workshops (introduction to, and advanced distance sampling methods) hosted by CREEM / St. Andrews University, Scotland. These workshops were attended to assist in data-preparation and analysis for estimating densities of minke whales from line-transect data collected during the 2010 field effort.

## **RESULTS**

### **Line-transect/Density Estimation**

Over 1600 minke whale boings were detected during on-effort acoustic survey periods. Bearings were calculated for many of these boings in-near real-time during field operations. These bearings resulted in localizations for just under 50 minke whales (Fig. 1). These data are still being reviewed and quality controlled, however, perpendicular distances to the track-line have been used to calculate a preliminary density estimate. This density estimate will be used to determine an average boing rate per animal for use in the DECAF/SECR density estimation effort by our collaborators.

### **Effects of Vessel Noise on Vocalization Rates**

Results of noise analyses indicated that minke whales are changing boing production rates in response to noise from our survey vessel. It is unclear at this time whether animals are going quiet or are moving away (or both) when the vessel passes nearby, but it appears that the effect is greater for boings that are neither the loudest, nor the faintest (Fig. 3). Interestingly, the loudest boings (i.e. the 'boing 5' category in Fig. 3) did not occur very often when the vessel was nearby, and did not increase when noise levels dropped, possibly indicating that minke whales are responding by moving away when the research vessel approaches. Further analysis is needed to determine which (or if both) of these possibilities have the most affect on line-transect detection functions. Data collected from the PMRF seafloor hydrophones should be able to answer these questions, but will require significant additional analyses.

### **Boing Analysis and Geographic Comparisons**

Preliminary results of boing comparisons from Hawaii, Midway (courtesy of Amanda Cummings and John Hildebrand of SIO) and the Mariana Islands analyzed using CART, T-tests, and ANOVA's indicated that there were some clear differences among these three areas (Table 2). Some results were consistent with our previous work and others (e.g. pulse-repetition rates) were not. We will need to increase sample sizes to adequately address these issues. Most promising is that using a suite of

acoustic variables measured from boings, the CART was able to differentiate boings from the different areas with 77% correct classification scores for boings originating from Guam, and 68% correct classification for those from Hawaii, even with the relatively small sample sizes (< 50) used to train and test the classifier. This work is ongoing and we will continue to add samples from Hawaii, the Mariana's, Midway Island and additional areas (e.g. French Frigate Shoals). We expect these data to better elucidate population structure of minke whales in the North Pacific and potentially allow examination of the degree of mixing of animals from these disparate areas.

### **Fast Research Vessel Validation work**

Although only 2 days of field effort was conducted with the faster R/V Tropic Bird trimaran, we were able to use a combination of a fixed hydrophone array and sonobuoys to detect, record and follow minke whales using their boings. Several technical difficulties were overcome, including the use of a stand-alone DC power to operate all acoustic systems (e.g. computers, the sound board, the GPS and the array). Due to its shallow depth and noise from the vessel, the fixed array was only useful at close ranges to vocalizing animals. Sonobuoys proved effective for monitoring at much greater ranges. Although we were unable to visually locate a minke whale, we demonstrated that a faster, but stable platform equipped with a combination of passive acoustic systems can be used to monitor and track individuals. Future efforts should seek to use even faster vessels (i.e. power catamarans with speeds up to 20+ knots) that can also operate quietly under sail or slow motor-sailing if necessary.

### **IMPACT / APPLICATIONS**

Acoustic based line-transect surveys resulted in numerous detections and a preliminary estimate of minke whale density and abundance for the study area (see Annual Report by Len Thomas for details). This estimate is important because to date, there are no estimates of minke whale abundance in the Hawaiian or other Pacific Island regions, not due to a lack of effort, but rather due to a paucity of sightings. This information is important for effective management and mitigation of human activities on this federally protected species. In addition, our results will be used as inputs in a related effort that is using seafloor hydrophones to estimate densities of minke whales from boings using SECR methods. Both of our efforts will provide new information but also new methods for estimating abundances of a species that is rarely sighted. It is likely that these techniques can be applied to other species and areas.

Our preliminary results on the acoustic behavior of minke whales are significant because they provides important insights into the effects of vessel noise on boing detection rates from survey vessels. These findings need to be considered in future survey efforts for this and other species that are sensitive to noise. Acoustic characteristics of minke whale boings are poorly understood, especially for populations in the North Pacific. We have determined that there are specific acoustic characteristics of the boings that can be used to identify animals from western and central (i.e. Hawaiian) North Pacific. We have been able to use these characteristics to successfully classify boings from these two main areas. These results are an indication that several populations or sub-populations likely exist. We will continue to add samples from these and other areas in the Tropical and sub-tropical Pacific which should help to further elucidate population structure in these regions.

The results of our efforts and the related efforts of our collaborators are providing important information about the distribution, abundance, population structure and acoustic behavior of a species that has rarely been encountered visually in the Central and western subtropical Pacific.

## RELATED PROJECTS

Related projects by Len Thomas and Steve Martin including the Density Estimation for Cetaceans from passive Acoustic Fixed sensors (DECAF) were conducted simultaneously with our effort. These projects are using density estimates derived from our effort to calculate average boing (cue) rate so that estimates of minke whale densities can be derived from seafloor and autonomous hydrophones. Dr. Thomas also is advising and assisting us in the analysis of the acoustic-line transect data from the 2010 field effort (see year-end report by Thomas).

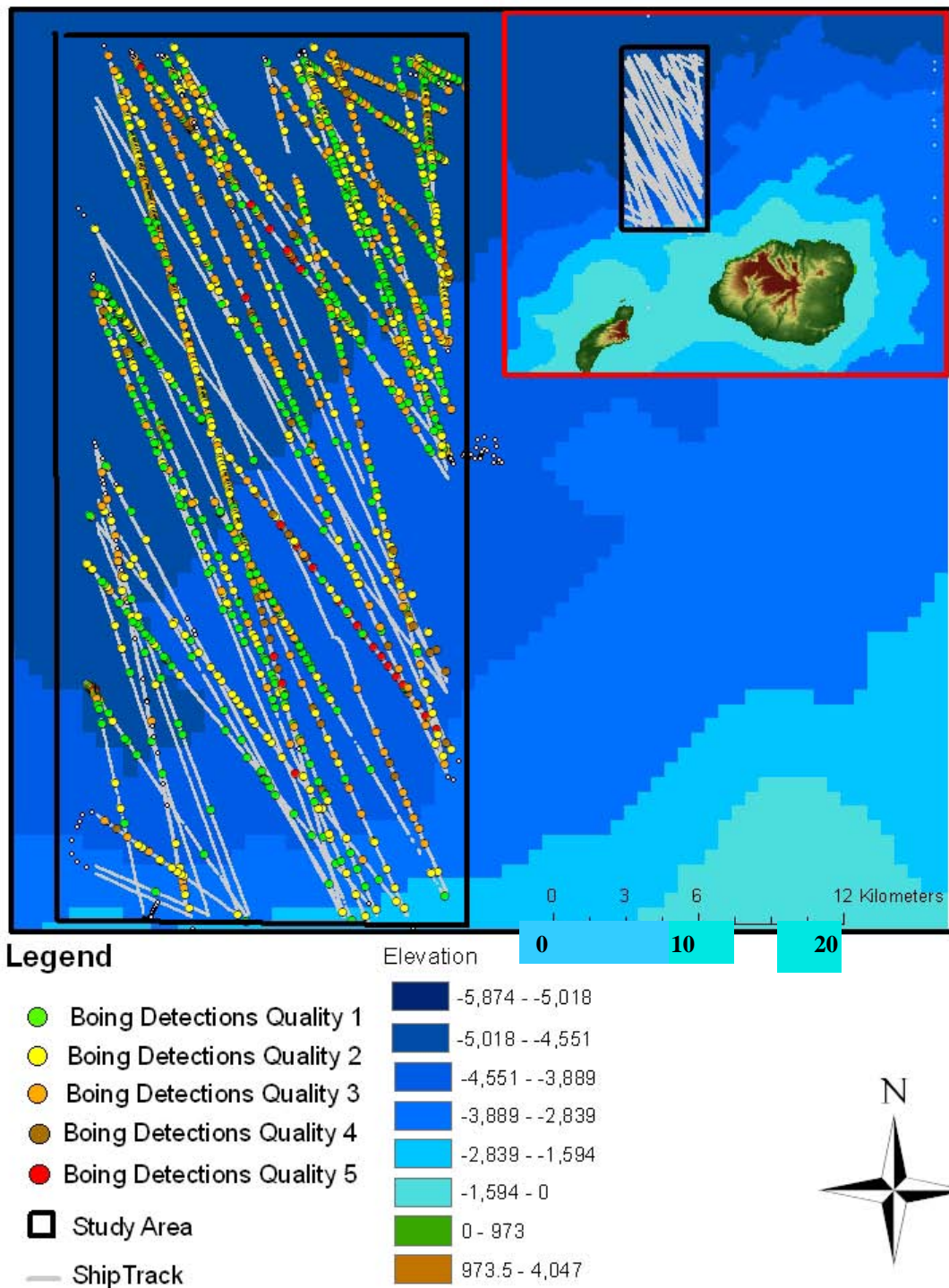
Other related projects include efforts to use acoustic data from seafloor arrays to localize and track minke whales using boings recorded from the PMRF BSURE array. These two projects are being conducted by Stephen Martin (SPAWAR-San Diego, CA) and Eva Nosal (University of Hawaii-SOEST). S. Martin collected acoustic data from the PMRF hydrophone array concurrently with our field effort and calculated locations based on a 2-D approach. Dr. Nosal used XBT data collected from our survey vessel in 2009 as sound speed profile inputs to develop a propagation model-based 3-D localization approach (see year end report by Nosal for details). Both these studies were validated using information from an animal that was acoustically detected and eventually visually located by our survey vessel in 2009. Martin is currently developing an automated processing algorithm to localize and track individual animals. This system should eventually allow the affects of vessel noise on vocalizing minke whales to be examined in greater detail than possible with survey only data (e.g. *individual* vocalizing animals can be monitoring before, during and after the research vessel passes nearby). In addition, localizations from line transect survey data can be directly compared to those determined from the seafloor array data. This effort might require significant additional analysis and should also include validation field studies to confirm any preliminary findings.

## REFERENCES

- Norris, T. F., Martin, S.W., Thomas, L. Yack, T., Oswald, J.K., Nosal, E-M. and Janik, V. 2010. The acoustic ecology and behavior of minke whales in the Hawaiian and Marianas islands: localization, abundance estimation and characterization of minke whale 'boings'. 2nd International Conference on the Effects of Noise on Aquatic Life Conference, Cork, Ireland. 15-20 Aug. (Proceedings to be published by Springer).
- Marques, T.A., L. Thomas, S.W. Martin, D.K. Mellinger, S. Jarvis, R.P. Morrissey, C. Ciminello, and N.DiMarzio, 2010. Spatially explicit capture recapture methods to estimate minke whale abundance from data collected at bottom mounted hydrophones. *Journal of Ornithology*.
- Rankin, S. and Barlow, J. 2005. Source of the North Pacific 'boing' sound attributed to minke whales. *J. Acoust. Soc. Am.* 118 (5): 3346-51.
- Thomas, L., S.T. Buckland, E.A. Rexstad, J.L. Laake, S. Strindberg, S.L. Hedley, J.R.B. Bishop, T.A. Marques and K.P. Burnham. 2010. Distance software: design and analysis of distance sampling surveys for estimating population size. *Journal of Applied Ecology* 47:5-14.

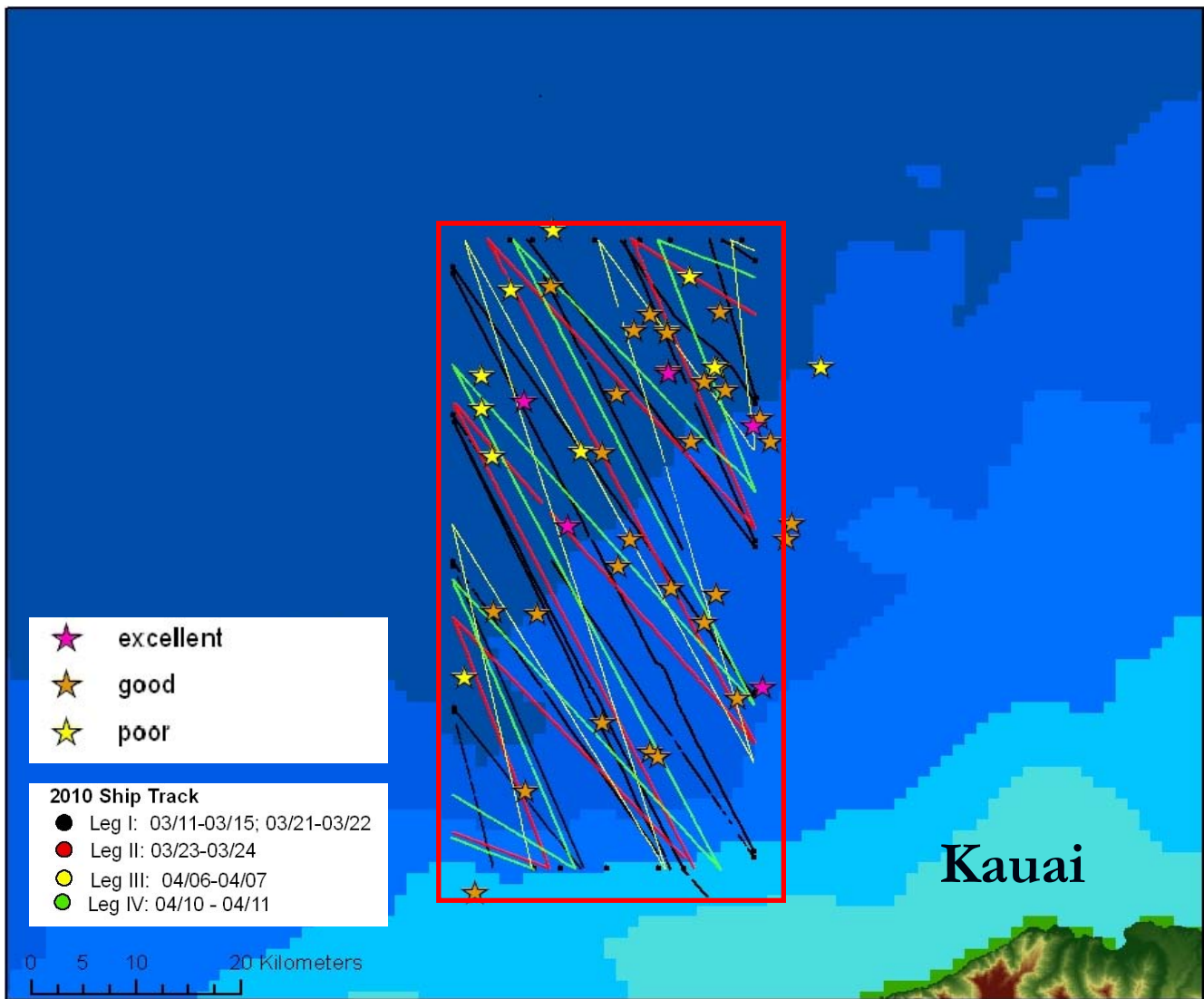
**Table 1. Line-transect survey effort completed in 2010 (excludes off-effort periods but includes some repeated transects in Leg I not used in the preliminary analysis). Additional survey effort in was completed in Leg I due to initial problems with the research vessel's navigation system.**

<b>Minke 2010 Survey Effort</b>			
<b>Leg</b>	<b>Number of Lines</b>	<b>Effort (hrs)</b>	<b>Effort (km)</b>
I	14	49:52:00	589.88
II	9	26:00:00	306.76
III	9	28:24:00	316.01
IV	9	23:47:08	307.56
<b>Total</b>		<b>128:03:08</b>	<b>1520.21</b>

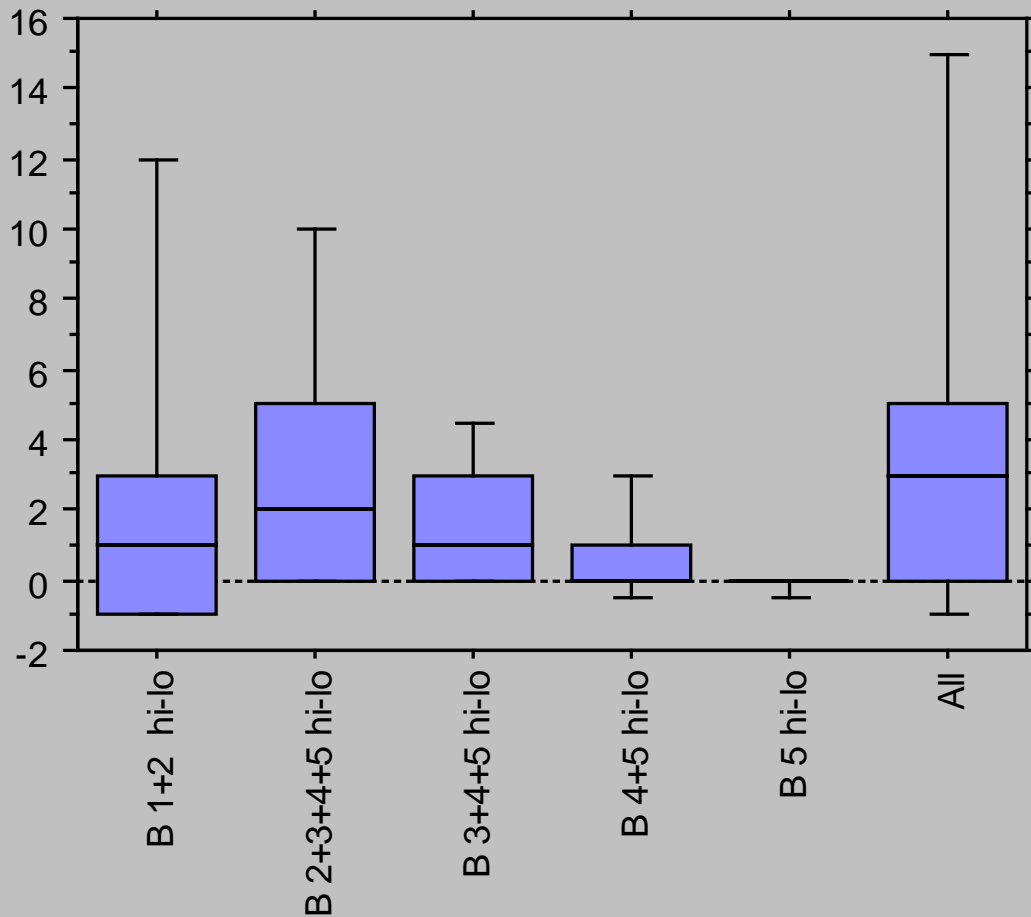


*Figure 1. Study area (~ 1900 km<sup>2</sup>) off Kauai with acoustic line-transects completed during the 13 days of effort (128 hours totaling 1500 km). Positions where boings were detected (plotted on the trackline) are indicated with small circles. Colors indicate relative intensity/quality (1 = low ; 5 = high).*





*Figure 2. Preliminary localizations indicated with stars (colors indicate localization quality).*



**Figure 3. Box-plot results of noise analysis on minke whale boing production. Plots show the median (center line), upper and lower quartiles (filled boxes) and ranges (whiskers) of the differences in boings counted during 10 minute periods of high noise and low noise. Positive values indicate that boings increased when noise was low or absent. Boings were first identified in all 10 minute periods of high and low noise, then ranked on a 1-5 scale with B1 being a faint or weak B5 being a loud/clear boing. Boings of each rank were then grouped for the analysis primarily to increase the number of observations but also to examine differences that relative distance the animal away from the survey vessel had on the effect size. Results indicate that rates of distant boings (i.e. animals that were far from the vessel) did not change significantly, whereas those at medium and close ranges did. Very few B5's were detected during high or low noise, possibly indicating animals were moving away from the survey vessel before it could pass close-by. Analysis of seafloor hydrophone recordings made during the same times should provide useful information to clarify these preliminary findings.**